LARGE REFRACTING AND REFLECTING TELESCOPES.

THE Yerkes Observatory, which has recently been completed and inaugurated, contains in its instrumental equipment the largest refractor in the world, the diameter of the object-glass spanning 40 inches.

The late Mr. Alvan Clark, the constructor of the lens in question, expressed the hope that still larger apertures might be successfully made, but he pointed out that the effect of flexure in larger discs was to be mostly feared, although he felt that it might be perhaps possible to still further increase the aperture without endangering the performance of the objective. Being therefore apparently near the limit to which such large object-glasses can be successfully constructed and mounted, it is only quite natural that attention should be turned to the other form of telescope, namely the reflector, and inquire whether this type of instrument is restricted in the same way as the refractor, or whether it can step beyond these bounds and open up fields which would otherwise be lost to us.

Discussions as to the capabilities of these two types of telescopes have been very rife, and while some observers hold that the reflector is the instrument of the future, others again take the other side and advocate refractors. It is now generally conceded that for definition the refractor is the instrument *par excellence*, but for purposes where light-grasping power is the main requirement the reflector takes the first place. In the cases of very large apertures reflectors can be made of diameters far exceeding anything that can be attempted for refractors. A point of initial importance in large instruments is the question of the focal length of the object-glass or mirror, as the case may be, for on this factor depends the length of the telescope tube. Now if this be of considerable length, the telescope mounting and dome have to be of considerable proportions, rendering the instrument both expensive and subject to many possible errors. To retain the size of the aperture of the instrument and reduce the focal length is a natural means of overcoming this difficulty, and this has been attempted in many instruments. Such a reduction is, however, accompanied by several optical drawbacks which detract from the efficiency of the instruments.

In the case of reflectors of large aperture and very short focal length a most striking deficiency becomes apparent, and, curiously enough, this has practically been passed unnoticed until Prof. Schaeberle (*Astr. Journal*, vol. xviii. No. 413) quite recently brought attention to it. So large is this source of bad definition, that he refers to it as a "fundamental optical defect." How he came to alight on this source of blurring factor will be best gathered from the following brief extract in his own words.

"On a very favourable night, I recently had the opportunity of testing the great Crossley reflector of the Lick Observatory, and found the surface of the same to be a practically perfect paraboloid of revolution; but on examining certain celestial objects—Saturn among others —I was very much surprised to find that the instrument failed most signally to come up to expectations. While puzzling and pondering over the probable cause of the poor results given by what I knew to be a finely figured surface, it occurred to me to ascertain the exact amount of the error introduced in the form of the image, resulting from the well-known fact that the focal point is not at the centre of curvature of the parabolic mirror."

To understand the origin of this bad definition, one must imagine a small circular disc situated in the focal plane of the paraboloid of revolution, and concentric with the optical axis. Viewing this disc from different points on the surface of the mirror, it is obvious that it will appear circular only when the eye is in the optical axis, but in all other positions it will appear elliptical, the eccentricities of the ellipses becoming greater the further the eye is moved away from the optical axis. Further, the angular diameter of both axes of the disc will decrease as the eye moves away from the optical axis, in consequence of the increase in distance from the focal point. The result of such a source of error as this would be that if the rays from the components of a double star be reflected by the mirror, the linear distance between their focal images as formed from different areas along any radius of the mirror will vary from a minimum for the area on the optical axis to a maximum for that area furthest away. In the case of a planetary disc, there will be produced a blurring effect caused by the numerous images of different sizes overlapping one another.

Having investigated this source of error, Prof. Schaeberle made a comparison of the efficiency of the more prominent reflectors now in use. The result is of such interest, that we must refer to it at some length.

In the following table the blurring effect for each mirror is tabulated in the fourth column, the fifth and sixth columns representing the computed difference of angular diameters of the outer ring of Saturn and the solar or lunar disc based on the given ratio of diameters.

Reflector	Diam. of mirror $= 2Rm$	Focal length $= F$	Max. ratio of diameters $= \frac{a}{r}$	Diff. of angular diameters for the given ratio		Limiting radius of field for best definition
				Saturn's outer ring	Sun or moon	
	Feet	Feet		"	"	"
Lord Rosse	6·0	55·0	1·0033	0·13	6	15
Common	5·0	27·0	77	0·31	14	7
Lassell	4·0	37·0	22	0·09	5	22
Melbourne	4·0	28·0	39	0·16	7	13
Paris	3·9	23·4	51	0·20	9	9
Crossley	3·0	17·3	57	0·23	10	9
Draper	2·4	13·0	64	0·26	12	8
Lassell	2·0	20·0	19	0·08	3	25
Roberts	1·7	8·2	78	0·31	14	6
Common	1·7	3·7	404	1·62	73	1
Schaeberle	1·5	12·3	28	0·11	5	19
Draper	1·3	13·0	19	0·08	3	25
Schaeberle	1·0	3·7	141	0·56	25	4

The last column gives the values for the limiting radius of the field of view of best definition for each telescope, on the assumption that the radius of the field of measured distances with the optical axis as centre, does not exceed a value which would introduce an error of more than 0″·05. The most striking feature of this column is the smallness of the fields in the several cases mentioned which are not influenced by this error.

A glance down the fifth column brings out clearly the fact that the smaller the ratio of focal length to diameter of mirror, the larger the difference of angular diameter of the objects observed. Thus in the case of the Draper, Schaeberle, and the two Lassell instruments, where this ratio is comparatively large, about 9 : 1, the differences are small, while for the two Common mirrors and Schaeberle's 12-inch, where the mean ratio is approximately 4 : 1, the differences increase very rapidly.

Not only will this blurring effect, caused by these differences of angular diameters of the images, be notably increased as the focal length is decreased, but the greater diameter of the image, and therefore distance from the optical axis, will bring this defect more in evidence.

The main result of the investigation, summed up in a few words, is that large parabolic mirrors having a ratio of focal length to aperture less than fourteen to one are, as regards definition, "theoretically unfit for making observations of extreme delicacy." It may be mentioned that this defect does not mar the efficiency of such instruments for certain kinds of work, such as spectroscopic, bolometric, &c.

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Thus it is gathered from Prof. Schaeberle's investigation that reflectors of large aperture must also be of correspondingly great focal length if the definition of the object to be observed is to be of the first order.

As refractors of large aperture are seldom made of such short focal lengths as are in question, it is unnecessary here to consider the effect of this source of bad definition.

Several interesting points with reference to the capabilities of large instruments have been brought prominently forward during the last few months, and may be appropriately referred to in this place. Thus Prof. Wadsworth (*Astronomical Journal*, vol. xviii. No. 414) has dealt with the efficiency of large refractors for visual observations of planetary details. He finds that from an optical point of view, it is a distinct advantage to increase the apertures of telescopes intended for visual use of planetary detail, such as fine linear markings, up to such a point where the atmospheric aberration will amount to about one-seventh or one-eighth period under the best conditions of observation. If this point be exceeded, then no advantage is obtained, the efficiency actually falling off; the tendency is for the faint lines under observation to be blotted out, instead of becoming more distinct. Indeed so sure is he of this, that he says the limit of efficient size is about reached between 30 and 35 inches, or the limit is very rapidly approached.

Another point of great importance *re* large apertures is that such telescopes cannot always be efficiently used unless the night be very fine and the air still. The well-known observer, Dawes, always used to judge the night by the aperture that could be employed. Thus he spoke of a one-inch night, two-inch night, up to an eight-inch night, this being the greatest aperture he possessed. As a matter of history, one may relate that a comparison of the drawings of Mars made by Sir Norman Lockyer with his six-inch refractor, and by Lord Rosse with his big reflector, showed that although both series were made at the same time, they displayed striking dissimilarities. Dawes, who had also made some valuable drawings at the same opposition, in discussing this question of dissimilarity, concluded that Lockyer's drawings were the more correct, since they were found to be exactly like those he (Dawes) had made, especially with regard to a certain marking which he had called the "double tooth."

Dawes, however, was no lover of large apertures, and on the occasion just referred to he was heard to repeat one of his favourite phrases, "What have the giants done?"

Apart, then, from the quality of the instrument employed, definition depends on the state of the atmosphere through which the light rays pass. On clear nights the question of the movements of the air is of the highest importance, and it is only on this movement that the aperture for any particular night can be gauged. In consequence of these air undulations, which vary in different currents from half an inch to several feet in length, the definition varies enormously.

In the case of a small aperture, and supposing the wave-length to be more than double the diameter of the object-glass, the image of the object under observation would only be bodily moved without confusion; for a large glass the image would be very considerably blurred.

Dr. T. J. J. See has recently (*Astr. Nach.* No. 3455) been making investigations on the sizes and movements of these aerial movements, and his paper on this subject indicates the importance of increasing our knowledge by more systematic study.

Thus it will be seen that in discussing the question of how large telescopes may be made to do useful work, a most important item to take into consideration is the locality in which they will be used. If such a spot be happily found, situated on a high plateau where the movement of the air is practically nil, then theoretically there seems no reason why apertures should be limited in size; but as such a condition as this is rarely if ever to be obtained, a limit is necessarily imposed on the diameters of object-glasses.

W. J. S. Lockyer.

THE WOBURN ABBEY DEER.

From the difficulty of obtaining an adequate series of specimens, either living or dead, the deer are one of the groups of large mammals with regard to which our present state of knowledge is decidedly not up to date, comparatively little advance having been made since the appearance of the late Sir Victor Brooke's well-known synopsis in the *Proceedings* of the Zoological Society for 1878. Fortunately the noble owner of Woburn Abbey, who takes a great interest in animals of all kinds, is endeavouring to get together as complete a collection as possible of these beautiful and interesting ruminants, or rather of such kinds as experience shows to be best suited to withstand the vicissitudes of the English climate. With characteristic liberality the whole of the magnificent collection now assembled is accessible to zoologists interested in this group of animals, and by its means considerable additions have already been made to our knowledge thereof. From the extent of ground much larger numbers of specimens of the same species can be collected than is possible in the limited space available in the Zoological Society's Gardens in Regent's Park; and the conditions existing in a large country park are, of course, far more favourable to the well-being and display of the animals than is possible in London.

In the Regent's Park the larger kinds of deer, such as the American wapiti, are generally, from necessity, represented by only two or three individuals at a time, but at Woburn these and other species are assembled in herds of considerable size. And as deer are remarkable for their seasonal variations in coat and colour, it is in such manner only that a full grasp can be obtained of these periodical changes. A further advantage is the opportunity of seeing closely allied species or varieties either in the same paddock or in near juxtaposition; while the facilities for studying the habits of the animals are infinitely in advance of what is possible elsewhere.

For a long period of years the domain at Woburn has been a deer-park where large herds of red and fallow deer wander at their own sweet will; and the undulating wooded ground alternating with level expanses of excellent pasture, and the numerous lakes and ponds dotted over the latter area afford an ideal situation for all animals of this class. Such foreign species as adapt themselves easily to these conditions, and do not make themselves objectionable by developing habits of ferocity, are allowed to run at large in the open park. Among these are Père David's deer, of Northern China, the elk, the Virginian deer, and the Japanese and Manchurian sikas; while muntjacs and roe run wild among the coverts. Such an amount of liberty cannot, however, be permitted to many of the species on account of their dangerous propensities; while it is found convenient or necessary to afford more protection from the wind and weather to yet other kinds. But even in the case of species deprived of their full liberty, the amount of space accorded them is ample, and quite different from what is practicable in domains of smaller magnitude. The American wapiti, for instance, live in a "paddock" of about 150 acres, surrounded by an eight-feet iron fence; and in the same enclosure, as shown in our first illustration, run the various races of sambar, as well as some of the sikas, and various other small species. A small herd of American bison are also among the denizens of this enclosure. Hard by, in a paddock of but little inferior dimensions, is a magnificent herd of

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